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Hydropower for sustainable energy development in Turkey: The small hydropower case of the Eastern Black Sea Region

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ABSTRACT

Turkey is a rich country from the point of variety and potential of renewable energy resources. Hydros, winds, biomass, solar and geothermal are important renewable and environmentally friendly sources for energy in Turkey. Turkey produces large amount of hydropower with a total gross hydropower potential of 433 TW h/yr, which is equal to 13.8% of the total hydropower potential of Europe. Technically useable potential is 216 TW h/yr and economic potential is 140 TW h/yr. The main aim of the present study is to investigate hydropower potential of Turkey and small hydropower plants in Eastern Black Sea Region for sustainable energy development in Turkey. The geography of Turkey especially, Eastern Black Sea Region supports and suitable the development of the small hydro plants to increase the energy generation and utilization of available water sources in Turkey. Besides, the paper deals with hydropower policies to meet ever increasing energy demand for sustainable development of Turkey.

Contents

1. Introduction

Energy is considered to be a key factor in the generation of wealth, social development and improved quality of life in all developed and developing countries in the world. Therefore, produced and consumed energy resources and especially renewable energy sources have a very important value. When the energy resources are used, some factors such as remaining reserves, geographical distribution, production shares, stability of pricing, commercial status, source reliability and especially environmental concerns should also be considered. In view of all these factors, renewable energy sources are standing out in energy generation [1–3].

Renewable energy sources such as solar, wind, hydropower, biomass and geothermal are potential candidates to meet global energy requirements in a sustainable way and supply 14% of the total world energy demand. These energy sources are primary, domestic, clean inexhaustible sources. In this regard, hydropower is already the most important renewable and sustainable energy source. Hydropower contributes one-fifth of the power generation

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of the world. In fact, it provides the majority of supply in 55 countries. For several countries, hydropower is the only domestic energy resource. Therefore, its present role in electricity generation is substantially greater than any other renewable energy sources in many developing countries including Turkey [4–7].

Renewable energy sources have been the primary energy sources in the history of the human beings. The availability of renewable resources is an asset for many developing countries. As a renewable energy source, water is such a natural substance that cannot be substituted by any material and the living beings are dependent on it. But, as a result of rapid growth of population and the expansion of irrigated agriculture and economic development and industry, water resources are being stressed both quantitatively and qualitatively. Waterpower resources are the basis for sustained renewable electricity generation. Multiple small-scale hydropower systems have low negative effects on nature and human beings [1,3].

2. Currently renewable energy outlook of Turkey

The development level of a country is directly related to its economic and social level. One of the most important factors that take an active role in achieving such development level is the renewable energy. Energy, which is the main requirement of sustainable development, can only be an impulsive force in industrialization and overall development of societies if it is supplied on time, in sufficient quantity and under reliable economic conditions low environmental impacts. The demand for energy increases rapidly in parallel with the population increase, industrialization and technological developments in Turkey and the other developing countries in the world [8].

Table 1
Renewable energy sources of Turkey in 2010.

Sources	Potential (MW)	Under construction (MW)	In operation (MW)
Hydropower	40,000	13,766	14,802
Wind	48,000	2,251	1,002
Geothermal	600	70	94

Table 2
Annual distribution of installed capacity of renewable energy sources in Turkey.

Years	Hydraulic	Geothermal	Wind	Other	Total (MW)
2000	11,175.20	17.50	18.90	23.80	11,235.40
2001	11,672.90	17.50	18.90	23.60	11,732.90
2002	12,249.90	17.50	18.90	27.60	12,304.90
2003	12,578.70	15.00	18.90	27.60	12,640.20
2004	12,645.40	15.00	18.90	27.60	12,706.90
2005	12,906.10	15.00	20.10	35.30	12,976.50
2006	13,062.72	22.90	59.00	41.30	13,185.90
2007	13,394.90	22.90	146.30	42.70	13,606.10
2008	13,828.70	29.80	354.70	59.70	14,272.90

The distribution of main renewable energy sources in Turkey is presented in Table 1. The most important renewable energy sources in operation are hydropower, wind and geothermal 14,802 MW 1002 MW and 94 MW, respectively. Annual distribution of installed capacity of renewable energy sources in Turkey is illustrated in Table 2. In 2000, the installed capacity of hydropower, geothermal and wind are 11,175 MW, 17 MW and 19 MW, respectively. In 2008, installed capacity of hydropower, geothermal and wind increased 23%, (70%) and 876%, respectively [9,10].

The distribution of renewable energy sources in the primary energy production of Turkey for the term from 1970 to 2009 is illustrated in Fig. 1. The energy sources used for the primary energy production are hydraulic energy, geothermal energy, wood, animal and vegetable waste. On average 43% of the primary energy production was met by the renewable energy in 1970. This percentage peaked with 50% in 1980. Thereafter, its share decreased and become to 33% in 2009. The contribution of the renewable energy sources as follows: 10% hydraulic, 6% geothermal, 12% wood and 4% animal and vegetable waste in 2009. Accordingly the largest energy source used in electricity production was wood. When use of renewable domestic energy sources is considered in terms of primary energy production, it decreased to 10% levels in 2009, compared with 1970s [8,11–13].

Turkey has almost all kinds of energy sources. However, Turkey is not rich in fossil fuel resources, except for lignite and with 11.4 billion tones of indicated resources. Hydraulic energy potential of the country is not enough to meet its energy requirement. Hence, more than half of the energy requirement is met by imported energy. The primary energy consumption of Turkey has increased over the years and the energy demand will further increase in the future. The development of the total share of renewable energy sources in primary energy consumption of Turkey is illustrated in Fig. 2 (for the term 1970 and 2009). The energy sources used for the primary energy production are hydraulic energy, geothermal energy, wood, animal and vegetable waste. The share of total renewable energy sources in overall consumption steadily decreased from 33% in 1970 to only 9% in 2009 [8,11–13]. Wood has remained the main source of energy consumed over the years despite the decrease in its share. On the other hand, the contribution of hydraulic energy to consumption has increased since 1974.

Recently, the rising level of global warming with its increasing effects on animals and agriculture is sourced by climate change.

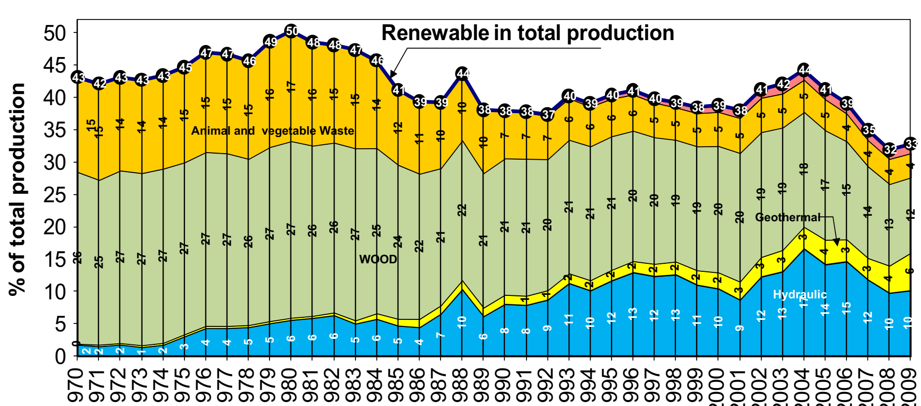


Fig. 1. During of the period 1970–2009, renewable energy sources and rates used in the primary energy production in Turkey.

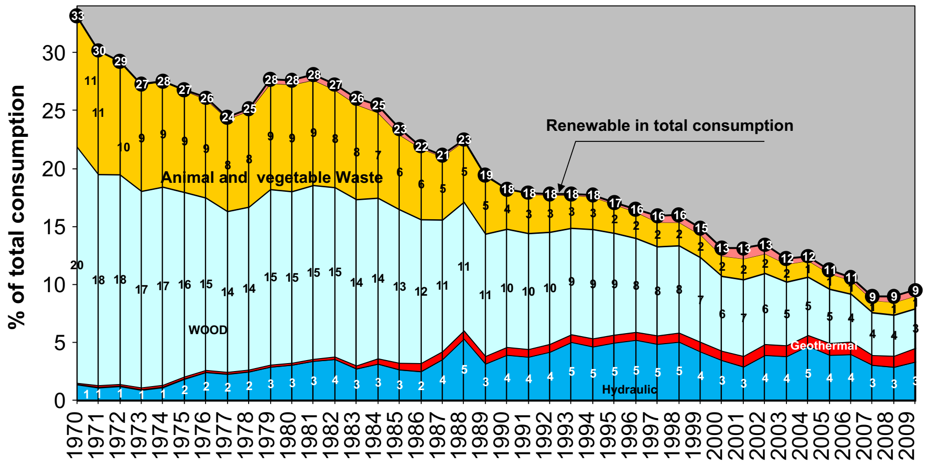


Fig. 2. (During of the period 1970 and 2009) Development of the total share of renewable energy sources in primary energy consumption.

Table 3
Projection of electric energy generation in Turkey [14].

Energy generation		2010	(%)	2023	(%)	2050	(%)
Thermal	TW h	176.00	77.2	231.00	52.2	385.00	47.5
Nuclear	TW h	0	0	36.0	8.1	72.00	8.9
Geothermal	TW h	0.18	0.1	1.90	0.4	7.60	0.9
Hydro	TW h	48.24	21.2	94.80	21.4	110.60	13.7
Wind	TW h	3.63	1.6	66.00	14.9	141.90	17.5
Sun	TW h	0.01	0	12.80	2.9	92.80	11.5
Total	TW h	228.06	100	442.50	100	809.90	100

Table 4
Projection of the installed capacity in Turkey for electric energy [14].

	2010	Rate (%)	2023	Rate (%)	2050	Rate (%)
Population	77,000,000		88,240,000		115,440	
Energy consumption (kW h/per)	2,750	–	5,000	–	7,000	–
Total energy need (TW h)	221.75	–	441.2	–	808.08	–
Installed capacity						
Thermal (MW)	32,000	66	42,000	38.5	70,000	31.0
Nuclear (MW)	0	0.0	8,000	7.3	16,000	7.1
Geothermal (MW)	94	0.2	1,000	0.9	4,000	1.8
Hydro (MW)	15,266	31.5	30,000	27.5	35,000	15.5
Wind (MW)	1,100	2.3	20,000	7.3	43,000	19
Sun (MW)	4	0.0	8,000	7.3	58,000	25.7
Total (MW)	48,464	100	109,000	100	226,000	100

Hence, increasing the electricity generation from renewable energy sources, called green energy sources, becomes more and more important for Turkey and the world as well. In 2023, the projection of electric energy generation of Turkey will be 442 TW h. In future, the shares of the energy sources in this production are shown in Table 3. Accordingly,, the largest energy source in 2023 will be thermal sources followed by hydro and sun energy sources (Table 3). In 2023, total the installed capacity of Turkey is projected to be 190.000 MW (Table 4).

3. Hydropower potential in Turkey

The term "Hydro" is a Latin word for water; therefore hydropower is made using the flow of water in a river or storing the water in a dam. Water is an essential resource that all known forms of life on the earth depend on. Water system operating dates from the dawn of civilization. Today, modern water operating dams and plants are used and spread to the developing world. In Turkey, hydro projects were set up by the Ministry of Public Works in the early 1930s. The first production started in the 60 kW hydro plants in Tarsus, which was used only for providing electricity lights for during the initial years of the Republic of Turkey. The installed capacity taken over by the Republic was 29,664 kW, and the electricity was available only in Istanbul, Izmir, Tarsus and Adapazarı [15,16].

Hydropower is presently utilized in over 160 countries. At end of the 2008, the distribution of installed hydropower capacity in the world is shown in Fig. 3. China has the largest hydropower installed capacity with 22% share. Followed by Brazil, USA, Canada and Russian Federation 9%, 9% 8%, and 6%, respectively. The installed capacity of Turkey is equal to 2% of the world. It should be noted that a comparison with installed capacity is not the same as that of generation, as many countries rely on hydropower less for base-load supply and more for load-following operations [17].

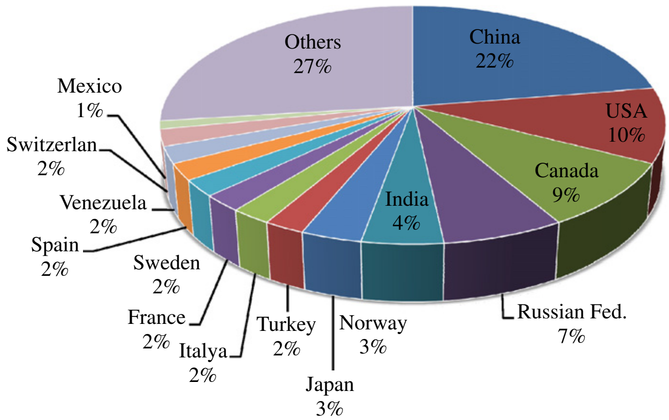


Fig. 3. Distribution of installed hydropower capacity at end-2008.

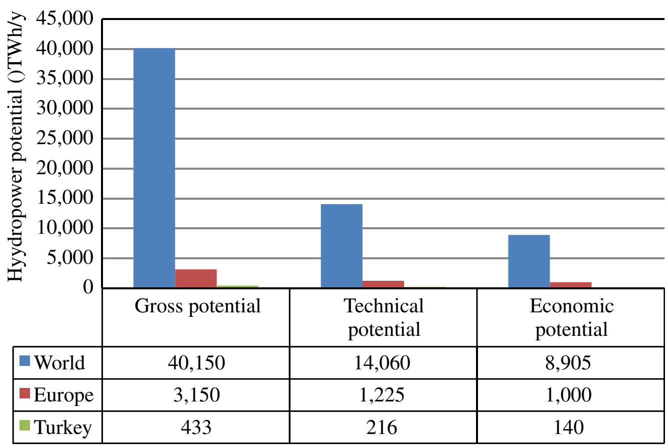


Fig. 4. Hydropower potential of Turkey compared with the world and Europe.

Table 5
Economic potential of hydroelectric plants in Turkey [18,20].

Current situation	Number of plants	Installed capacity (MW)	Rate (%)	Electricity generation (GW h/yr.)	Rate (%)
In operation	228	14,503	32	50,487	35
DSI	57	10,784			
Others	115	3000			
Under construction	148	8600	18	20,000	14
DSI	23	3600			
Others	125	5000			
Planned	1418	22,700	50	72,000	51
DSI	17	4000			
Others	1401	18,700			
Total	**1794**	**45,803**	**100**	**142,487**	**100**

Table 6
Comparison of Turkey hydropower potential with some European countries.

Country	Technical hydropower potential (TW h/yr)	Economically feasible hydropower potential in 2005	Actual generation in 2005 (TW h/yr)	Development economical potential (%)
Turkey	216	130	47.87	36
Norway	200	187	136.6	73
Sweden	100	85	72.9	86
France	100	70	56.5	81
Italy	105	65	42.9	66
Austria	75	56	38.6	69
Switzerland	43	41	33.1	81
Spain	66	32	23	72
Germany	25	20	26.7	134
United Kingdom	3	1	7.9	789

Turkey does not have enough primary energy sources such as fuel oil and natural gas, but has abundant hydropower energy potential. Recently, Turkey, therefore, makes some important plans for the development of its substantial hydropower potential. The gross hydroelectric power potential depends on the foreseen development projects of the region. Gross hydropower potential of Turkey, which is a function of topography, geology and hydrology, is about 433 TW h/yr, which corresponds with 1.1% of the total hydropower potential of the world and 13.8% of Europe. Almost half of the gross potential of Turkey is technically exploitable. Turkey's technical and economic hydropower potential is 216 TG-h/yr, and 140 TW-h/yr, respectively. These are equal to 17% and 14% of the total hydropower potential of Europe, respectively (Fig. 4). Currently, 25.6% (35.8 TW-h) of this economically-feasible hydropower energy potential is generated annually by 228 hydroelectric power plants in operation within a total installed capacity of 14,503 MW. The economic potentials for installed hydroelectric power capacity and electricity generation are 45.803 MW and 142.487 GW-h/yr, respectively (Table 5). Shortly the gross potential shows the hydroelectric energy production upper limit of a river region, a potential that is made up by the existing height and average flow rate. Current hydropower generation capacity accounts for 32.8% of the nation's total installed capacity [18,19]. The Turkish government hopes that hydro capacity will expand to 35,000 MW by the year 2020 [1].

A comparison of hydropower potential of Turkey with some European countries is shown in Table 6. Technical hydropower potential of Turkey is 216 TW h/yr. Average annual total production is 47.87 TW h/yr, which corresponds to 36% of the total economical potential [21,22].

Hydropower with dam and with run of river is important renewable energy source. Turkey has made great strides in development of water resource for irrigation, power generation, flood control and other purposes. The installation of dams and run of river has allowed to save the water from its all seasons of rainfall to use throughout the year. The most important rivers in Turkey are Euphrates and Tigris. In 1977, the Southeastern Anatolia Project (GAP) with 13 projects was built developed on rich water sources of these two rivers. Major hydro dams are Ataturk dam (2405 MW installed capacity) in Sanlıurfa; Karakaya dam (1800 MW) in Diyarbakır; Keban dam (1330 MW) in Elazığ. The important small hydropower dams are Doğankent (74.5 MW) in Giresun; Kadıncık.I (70 MW); Kadıncık II. (56 MW) as seen in Table 7 [18,23,24].

Hydroelectric power in Turkey accounts for about 30% of electricity supply the in renewable energy sources with additional potential for growth. Turkey's electric power demand has been growing steadily. The share of renewable energy sources in electricity generation over the years from 1950 to 2009 is shown in Table 8. Net electricity generation in Turkey has more than doubled over the past decade, with thermal and hydropower sources having the largest large production rate. In 1950, total gross electricity production of Turkey was 789 GW-h, 96.2% (759 GW-h) of this produced from thermal power plants and the reminder 3.8% (30 GW-h) from hydropower plants. The electricity generation from thermal and hydropower sources has increased and reached to 80.6% (156,923 GW-h) and 18.5% (35,959 GW-h), respectively, in 2009 [25].

Energy demand of Turkey increases rapidly. But, Turkey increases the energy production decreasing its dependence on foreign energy supplies. The government attempts to enhance the

Table 7
Hydropower plants with dam above 100 MW and run of river above and 50 MW in Turkey.

No	Name of plant	Plant type	Location	Number of units	Installed cap. (MW)	Gross generation (GW h)	Project generation	
							Average (GW h)	Firm (GW h)
1	Atatürk	Dam	Sanliurfa	8	2405	4525	8900	7400
2	Karakaya	Dam	Diyarbakir	6	1800	4557	7354	6800
3	Keban	Dam	Elazığ	4	1330	3959	6000	5820
4	Altınkaya	Dam	Samsun	4	703	436	1632	1236
5	Berke	Dam	Adana	3	510	1500	1668	921
6	Borçka	Dam	Artvin	2	301	937	1039	600
7	H. Ugurlu	Dam	Samsun	4	500	1658	1217	820
8	Gökcekaya	Dam	Eskişehir	3	278	420	562	460
9	Catalan	Dam	Adana	3	169	627	596	270
10	Dicle	Dam	Diyarbakır	2	110	186	298	228
11	Gezende	Dam	Içel	3	159	476	528	130
12	H.Polatkan/sarıyer	Dam	Ankara	4	160	313	400	328
13	Hirfanlı	Dam	Kırşehir	4	128	92	400	178
14	Karkamış	Dam	Gaziantep	6	189	286	652	462
15	Batman	Dam	Batman	2	198	326	483	196
16	Aslantaş	Dam	Adana	3	138	650	569	360
17	Sır	Dam	K.maras	3	284	691	725	408
18	Özlüce	Dam	Bingol	2	170	496	413	290
19	Obruk	Dam	Çorum	4	212	182	473	337
20	Muratlı	Dam	Artvin	2	115	449	444	400
21	Menzelet	Dam	K.Maraş	4	124	460	515	435
22	Kırıçkaya	Dam	Sivas	2	120	344	332	277
23	Torul	Dam	Gümüshane	2	106	326	322	130
24	Birecik	Dam	Sanlıurfa		672	–	2518	1801
25	Doğankent	Run-of river	Giresun	4	75	327	314	62
26	Kadıncık.I	Run-of river	Içel	2	70	288	345	190
27	Kadıncık.II	Run-of river	Içel	1	56	223	320	200
28	Şanlıurfa	Run-of river	Şanlıurfa	2	52	157	124	–

Table 8
Electricity production from thermal, hydropower, geothermal and wind sources during the period 1950–2009 in Turkey.

Year	Thermal (GW h	Hydropwer (GW h)	Geothermal	Wind	Total (GW h)	Percent of thermal	Percent of hyropower
1950	759	30	–	–	789	96.2	3.8
1960	1814	1001	–	–	2815	64.4	35.6
1970	5590	3033	–	–	8623	64.8	35.2
1980	11,927	11,348	–	–	23275	51.2	48.8
1985	22,168	12,045	6	–	34219	64.8	35.2
1990	34,315	23,147	80	–	57542	59.6	40.2
1995	50,620	35,541	86	–	86247	58.7	41.2
2000	93,934	30,879	75	33	124,921	75.2	24.7
2001	98,563	24;010	89	62	122,724	80.3	19.6
2002	95,563	33;684	104	48	129,399	73.9	26.0
2003	105,101	35;326	89	61	140,577	74.8	25.1
2004	104,464	46,084	93	57	150,698	69:3	30.6
2005	122;242	39,560	94	59	161,955	75.5	24.4
2006	131;835	44,244	94	126	176,299	74:8	25.1
2007	155;196	35;851	156	355	191,558	81.0	18.7
2008	164,139	33,270	162	846	198,417	82.7	16.8
2009	156,923	35,958	436	1495	194,812	80.6	18.5

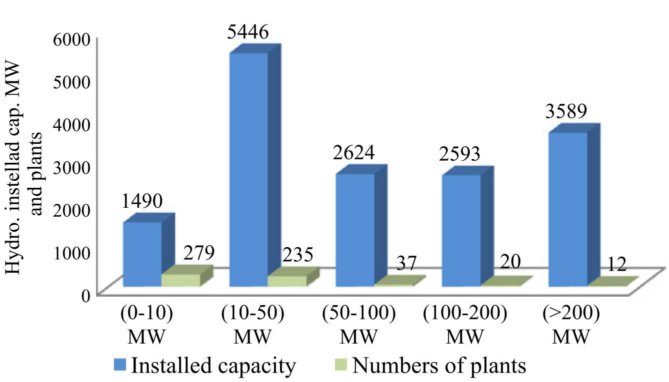


Fig. 5. Distribution of the hydropower installed capacity and numbers of plants [32].

utilization of current sources and to promote the exploration of renewable energy resources. In this regard hydropower is regarded as one of the most stable and economic sources for clean energy amongst the renewable energy alternatives in Turkey.

4. Small hydropower potential of Turkey

Hydro generation has contributed to almost 19% of total power generation in world. The generation can be classified based on its capacity: large, small, mini and micro. As for small hydro generation, there is still no internationally agreed definition of ‘small’ hydro but the upper limit varies between 2.5 and 25 MW. A maximum of 10 MW is the most widely accepted value

worldwide. In Turkey, the upper limit is accepted as 50 MW. In addition, small, mini and micro-hydro plants are usually defined as plants less than 10 MW, 2 MW and 100 kW, respectively. Small-scale hydro's turbine is used mostly a type of 'run of river,' so does not involve the construction of large dams and a little or no water is stored. In medium (5 m < head < 15 m) or high-head (head > 15 m) installations water is carried to the forebay by a small canal. Low-head installations (head < 5 m) generally involve water entering the turbine almost directly from the weir [26–28].

Table 9
Comparison of average capital cost for some source in the World and Turkey.

Type of source	Average capital cost in the world (€/kW)	Average capital cost in Turkey (€/kW)
Small Hydropower plant	1000	650
Wind	920	900
Geothermal	1230	1440
Solar PV	5400	NA

Table 10
Operating and investment costs of small hydro power in European countries.

Country	Operating cost (€cent/kW h)	Investment cost (€/kW)
Belgium	1.8	3700–4960
Germany	5	4000–6000
Greece	2.4–4.2	1000–2000
Spain	3.5–7	1000–1500
France	–	1200–3000
Ireland	3.75–9.1	1500–3000
Italy	5–10	1500–3000
Austria	3.6–14.5	2900–2500
Portugal	–	1300–2500
Finland	3–3.5	2200
Sweden	4–5	1500–2500
UK	5–7	2000–4800
Turkey	1	300–1000

In most of the sites of small-hydro plants the primary requirement of the local community is water for irrigation of agricultural land as their survival depends upon it. Therefore, many of small hydro power plants are normally operated to serve customer in remote area. When electricity and water are available, the living standards will be enhanced by better education, internet, job opportunities, communication and others facilities. Also, they create job opportunities in rural areas and thus can prevent migration to other places [29].

Hydro-generation tends to reduce environmental impact since it is not required to build large dams. Hydro power technology largely relies on its plant design and characteristics including the location of water intake, penstock, head size, water flows and the turbine types. Those are the factors that affect the efficiency and maximum power output of the turbine. Due to the structure of the river, small hydro plants are normally developed on low head [27,30].

In Turkey, the development of small hydropower plants started in 1902. Since, then, municipalities in rural areas have installed many hydropower plants that were operated by private companies and by some DSI (Hydropower State Hydrologic). In the period of 1930s, a Visera power plant with a capacity of 1 MW was installed in Trabzon city. The increasing demand on electricity, a number of small hydropower plants were installed from 1950s to the 1960s.A total installed capacity reached 38 MW in 1955 [31]. In Turkey, distribution of hydropower installed capacity and numbers of the plants are shown in Fig. 5. While, 279 of hydropower plants are between 0–10 MW and their installed capacity is 1490 MW. There are only 12 hydropower plants with 200 MW capacities.

The use of SHEPs (Small Hydroelectric Power) is important for sustainable development and economic growth in Turkey. SHEPs have the lowest capital cost per kW among the whole kinds of renewable energy alternatives in Turkey. Table 9 presents a comparison of capital cost of some renewable energy sources in the world and in Turkey. Furthermore, the investment and operating costs in Turkey are fairly lower than those in European countries (Table 10). These low costs offer attractive opportunities for the domestic and foreign entrepreneurs to make more investment on small hydropower plants in Turkey [22,33,34].

Table 11
Turkey's small hydropower potential.

Potential	Generation		Capacity (MW)
	GW h/yr	%	
Gross theoretical	50,000	100	16,500
Technical feasible	30,000	60	10,000
Economically feasible	20,000	40	6500
Economically feasible potential that has been developed	664	3.3	175
Remaining economically feasible potential	19,336	96.7	6325
Remaining economically feasible potential taking into account environmental constraints	19,300	96.7	6325

Table 12
Current situation of Turkey's dams and HEPs, including in operation and under construction.

		In operation			Under construction/scheduled		
		DSI	Others	Total	DSI	Others	Total
Dam	Number	655	18	673	145	1	146
	Large	242	18	260	63	–	63
	Small	413	–	413	82	1	83
HEP	Number	57	115	172	23	235	258
	Installed capacity (MW)	10,784	2916	13,700	3576	7,270	10,845
	Production (GW h/yr)	38,410	9461	47,871	11,555	27,849	39,404
Irrigation (10^6 ha)		3.06	2.22	5.28	0.23	–	0.23
Water supply (bcm)		2.58	0.58	3.16	0.50	–	0.50
Flood control area (10^6 ha)		1	–	1	0.4	–	0.4

Table 13
Present and potential of hydroelectric power in Turkey in 2006.

	Number of power stations	Total installed capacity (MW)	Proven production (GW h/yr)	Total annual production (GW h/yr)
Present hydropower plants				
In production > 10 MW	74	193	287	722
In production < 10 MW	68	12,595	33,273	45,208
Under construction > 10 MW	8	45	151	228
Under construction < 10 MW	32	3152	6207	10,290
Present total	182	15,985	39,918	56,448
Future possible potential				
> 5 MW	164	366	571	1,848
5–10 MW	82	610	897	2,587
10–50 MW	187	4727	9234	18,959
50–100 MW	51	3692	7734	13,001
100–250 MW	37	5,815	11,824	19,308
240–500 MW	10	3250	5620	10,688
500–1000 MW	2	1053	2054	3,173
1000 < MW	1	1200	2459	3,833
Future total	534	20,713	40,393	73,398
Total	716	36,698	80,311	129,846

Table 14
The status of hydropower in Turkey in 2011.

	In operation	Under construction	Project	Planned	Master plan	Preliminary survey	Total
Total number	142	40	15	175	95	259	726
Installed capacity (MW)	12,788	3,197	3,543	7,334	5,098	4,858	36,819
Energy (GW h/yr)	45,930	10,518	10,783	26,667	17,732	18,648	130,278



Fig. 6. Eastern Black Sea Region.

The gross theoretical small hydropower generation and capacity of Turkey is 50,000 GW h/yr and 16,500 MW, respectively (Table 11). The technically and economically feasible potential is 30,000 GW h/yr and 20,000 GW h/yr, respectively, in addition that a huge untapped potential exists for SHEP in Turkey. Remaining potential of SHEP for Turkey is 19,336 GW h/yr, corresponding to approximately 96.7% of economically feasible potential [22,35].

In 2009, Turkey has constructed a total of 673 dams in operation with 146 dams under construction. 260 of these dams are constructed as large dams and 413 of these are as small dams (Table 12) [36].

Table 13 shows present and future potential of hydroelectric power and Table 14 indicates the status of hydropower plants in Turkey [18,37].

5. Small hydropower potential of the eastern Black Sea Region of Turkey

The Eastern Black Sea Region (EBSB) is located on the north eastern coast of Turkey. The region is surrounded by the Eastern Black Sea Mountains on the south and Black Sea on the north. The region border starts from Georgia boundary and reaches Terme stream in the east of Samsun city. Total n surface area of the region is about 24.077 km^2. The region is separated by valley from the Black Sea in to the south zones. The Eastern Black Sea Region's cities and rivers in the region are shown in Fig. 6 [38].

Turkey is divided into 26 surface hydrological basins. Annual average flows of these basins amount to about 186 km^3. While Turkey's basin yields vary, the Euphrates and Tigris basin account for 28.5% of total potential of the country. Among the rest of these

hydrological basins in Turkey, the EBSB has great advantages from the view point of small hydropower potential without storage to water or large hydropower potential, which most of the installed attracts attention of private sector. Because, the most important characteristic of the region is that it takes great amount of rainfall in every season. Moreover, the region has very sharp valleys and there are a lot of steep streams with considerable discharges and heads. Therefore, the EBSB is preferred by private companies and the government. With the effect of the topographic factors, the rainfall increases from the east of Trabzon and to Rize. The values of the average annual precipitation in the region's cities are shown in Table 15. Annual average precipitation is 641 mm in Turkey [18,28,39]. This indicates the hydropower potential of the region is covered by very sharp valleys and has a numbers of very steep streams with important amount of flow rate and head. The sharp valleys and steep streams are suitable for small hydropower plants. Small hydro dams are quite small and usually just a little weir. Since they do not store the water, they do not have adverse effect on the local environment like large hydropower [38,40].

Topographical and hydrological conditions of the region are advantageous to establish a numbers of small hydropower plants. Therefore, the water and head potential points along the rivers and their tributaries existing especially in hilly rivers basins should be determined. If existing rivers, lakes, and their tributaries are reevaluated in terms of their head potential points, so there might be many available sites to install small hydropower plants in the region [41].

Turkey has been divided into 26 river basins. But almost %95 of its hydropower potential is distributed into main rivers basins which are mostly situated on the mountainous areas. Turkey's biggest hydropower plants were constructed on the Euphrates and Tigris rivers. Moreover, the Black Sea Region, which has steep and rocky mountain that extend along the coastline, has a considerable small hydropower potential. Especially, Eastern Black Sea Region is of very importance in terms of small hydropower potential (Table 16) [37,42].

The total amount of installed capacity and annual average energy generation of the 296 hydropower plants in the region are installed by DSI and private sector are 4585.41 MW and 16.160.24 GW h/yr, respectively. There are 181 of the small hydropower plants in the region (Table 17). Total amount of installed capacity and annual average energy generation of these smalls hydropower plants are 861 MW and 3213 GW h/yr, respectively. The small hydroelectric energy potential of this region will be able to meet 16% of the economically feasible small hydroelectric energy potential of Turkey. The total amount of installed capacity and electricity generation of the dams (Atasu, Topçam, Kürtün and Torul) in the region are 253 MW and 746 GW h/yr, respectively. Moreover, there are 30 mini hydro power plants (500 kW < potential < 2 MW) in the region with their installed capacity and electricity generation production of 41.80 MW and 179.67 GW h/yr, respectively. Also, micro hydro potentials (10 kW < potential < 500 kW) are very suitable for the condition of the energy demand in high flatland and hamlets. Installed capacity and electricity generation of the micro hydro plants are 0.82 MW and 3.18 GW h/yr, respectively [18,38].

6. Environment effects

6.1. Hydropower's effect on the environment

The hydropower energy production is associated with both water and renewable energy production. Water sources are one of

Table 15
The period of 1970–2010, the average rainfall of the EBSB.

	January	February	March	April	May	June	July	August	September	October	November	December	Total average
Rize	210.5	175.7	144.1	92.3	99.6	135.7	148.5	182.6	249.7	300.5	256.4	246.0	2241.7
Giresun	116.3	89.6	87.7	81.5	66.3	80.9	77.5	90.3	125.3	168.4	151.3	122.6	1257.8
Ordu	93.8	80.7	75.5	73.9	55.0	76.3	62.7	62.8	83.8	135.8	126.6	107.1	1034.1
Trabzon	74	60.7	58.8	60	50.9	49.2	37.3	46.5	78.4	119.5	100.2	85.3	821
Artvin	90.7	72.7	59.8	56.4	53.4	49.7	30.8	30.2	33.8	62	78.4	96	714.1
Samsun	58	50.2	56.9	51.1	48.0	48	31.7	36.7	52.9	91.9	80.2	76.9	691.8
Gumushane	33.8	32.8	41.5	61.3	67.6	45.5	12.5	15.20	21.80	47.3	44.9	40.0	460.9
Bayburt	26,5	28	41.2	61.4	68	50.8	20.3	15.9	21.8	47,3	35.3	28,7	442.1
Total	704	590	566	538	509	536	421	480	668	973	873	803	7664
Turkey	78.1	70.2	64.5	59.6	48.1	32.3	18.9	18	27.2	59.1	75.4	89.5	640.9

Table 16
Economically feasible hydropower potential of major Turkey rivers Basins in 2006.

River basin	Energy potential (GW h/yr)	Power potential (MW)	Drainage area (km^2)	Runoff (Tm^3/yr)
East Black Sea	13,194	3,900	24,022	14
West Black Sea	2,149	642	29,682	10.04
Çoruh	10,973	3,247	19,894	6.46
Euphrates	37,823	9,555	120,917	33.48
Tigris	16,562	4,890	51,489	21.81
Seyhan	6,957	1,788	20,731	7.06
East Mediterranean	6,749	1,856	22,484	12.27
Kızılırmak	6,420	2,116	78,646	6.28
Ceylan	5,996	1,779	21,222	7.21
Antalya	5,345	1,437	22,615	7.76
Yeşilırmak	4,984	1,257	36,129	5.54
West Mediterranean	3,240	881	14,518	11.24
Sakarya	2,585	1,191	56,504	6.03
Aras	2,692	868	27,548	5.54
Total	125,669	35,407	546,401	155

Table 17
Hydropower potential of the EBSB.

Province	Status of project	Total hydropower potential			Small hydroelectric potential		
		Number of project	Installed capacity (MW)	Electricity output (GW h/yr)	Number of project	Installed capacity (MW)	Electricity output (GW h/yr)
Giresun	In operation	1	31.29	99.15	–	–	–
	Under construction	25	663.81	2208.02	10	51.27	191.75
	Feasibility report ready	32	423.39	1365.25	20	98.27	342.61
	Signed water right consensus	5	65.81	203.68	3	10.19	31.31
Gumushane	In operation	1	103.50	315.67	–	–	–
	Under construction	5	71.33	195.26	4	22.53	79.40
	Feasibility report ready	13	82.65	263.00	11	43.74	147.10
	Signed water right consensus	2	54.00	133.63	–	–	–
Rize	In operation	–	–	–	–	–	–
	Under construction	23	610.46	2327.56	6	35.51	155.63
	Feasibility report ready	29	444.67	1657.75	19	85.21	342.43
	Signed water right consensus	5	66.20	285.83	1	1.22	6.38
Trabzon	In operation	3	64.60	282.15	–	–	–
	Under construction	40	429.70	1614.79	28	168.85	640
	Feasibility report ready	48	339.11	1106.28	42	166.02	593.69
	Signed water right consensus	10	161.24	611.33	7	44.17	185.35
Ordu	In operation	–	–	–	–	–	–
	Under construction	1	99.00	369.42	–	–	–
	Feasibility report ready	20	209.89	746.57	12	56.11	199.49
	Signed water right consensus	13	242.39	909.08	5	35.11	136.23
Artvin	In operation	–	–	–	–	–	–
	Under construction	–	–	–	–	–	–
	Feasibility report ready	10	45.31	163.22	9	29.49	107.97
	Signed water right consensus	3	118.26	535.65	1	6.75	32.96
Samsun	In operation	–	–	–	–	–	–
	Under construction	–	–	–	–	–	–
	Feasibility report ready	3	5.80	20.95	3	5.80	20.95
	Signed water right consensus	–	–	–	–	–	–
Small hydropower potential (2 MW < P < 10 MW)					149	817.94	3030.40
Mini hydropower potential (500 kW < P < 2 MW)					30	41.80	179.67
Micro hydropower potential (20 kW < P < 500 kW)					2	0.82	3.18
Total SHPPs potential (p < 10 MW) which will be made by private sector					**181**	**860.56**	**3213.25**
Hydro potential of Atasu and TopçamDams will be made by private sector			4198.02	14,943.27			
In operation hydro potential of Kürtün and Torul Dams			387.39	1,216.97			
Large hydro potential (P > 10 MW)	115		3724.85	12,947.00			
Atasu dam	1		5.00	27.00			
Topçam dam	1		60.00	199.00			
Kürtün dam	1		85.00	198.00			
Torul dam	1		103.00	322.00			
Total dams	**4**		**253.00**	**746.00**			
Total hydropower potential in EBSB	**296**		**4585.41**	**16,160.24**			

the important sources that support all forms of life on the earth where billions of people lack access to safe drinking water and adequate energy supplies. Unfortunately, water sources are not sufficient or unfairly distributed all area. Some regions of the earth do not have adequate water sources with drought and have scarce water sources in it is estimated that one third of the world's population lives in areas with water shortages, 1.1 billion people have no access to safe drinking water 2.6 billion people are without adequate water for sanitation and approximately 1.6 billion people cannot access to even electricity. On the other hand, in other parts of the world, flood disasters cause people death. In those regions, hydropower plant, dams and reservoirs have been installed for collecting, storing and managing water require to sustain the daily needs. Hydropower also supports some important features such as flood control, irrigation and access to safe drinking water. At the end of 2008, global installed hydropower capacity stood at about 874 GW [17,43–45].

Hydropower produces essentially no harmful emissions, in contrast to burning fossil fuels, and is not a significant contributor to global warming through (e.g., CO_2)SO_2)NO*x*. Hydropower plants do not have environment impacts such as acid rain or atmospheric pollution. Environmental impacts are limited to changes in the water line for dam (Table 18) [16,43,45,46].

Hydropower resources are widely spread around the world and critically important for many countries. Potential exists of hydropower in about 150 countries, and about 65% of the economically feasible potential remains to be developed. Besides, hydropower is a proven and well advanced technology with modern power plants providing the most efficient energy conversion process, which is also an important environmental benefit. Moreover, it has lower operating and maintenance costs and longer plant life compared with other large scale generating options. Hydro plant may operate up to 50–100 yr. Hydropower fuel is water, and never subject to fluctuations in the market. Hydropower releases no directly CO_2 to environment. Today, in view of the growing concern for greenhouse gas emissions and increased demand for energy, hydropower plays a major role in energy policies of the countries with abundant water sources. The other significant benefits of hydropower are control flooding, regulate water supply, increase air quality, improve living conditions, contributes fresh water storage, reduce greenhouse gas, irrigate land and prevent erosion.

The main disadvantage of hydropower is relatively high initial capital costs for the capacity installed. Dams built for hydropower plant causes some social and environmental concerns. These concerns include effects of changing river flows on ecosystem regimes, flooding of extensive land areas resulting in relocation of residents and loss of agricultural land, silt deposition and impact on certain sensitive species. Mini hydro and small-scale hydro dams could avert some of social and environmental problems. They could also reduce power shortage vulnerability during drought seasons experienced in the large hydro plants. Its significant disadvantage is dependence on rainfall, which very vary from year to year.

Table 18
Advantages and disadvantages of the hydropower energy sources.

Advantages	Disadvantages
Economic aspects	
Generally low operation and maintenance cost	Relatively high initial capital cost
Provides the cheapest way to create electricity in the modern world.	
Equates to only one cent for every kilowatt-hour produced	
Provides long live span (50–100 years)	Irregular precipitation season
Provides safety service	Requires long term planning
Uses advanced technology	Requires long term agreements
Provides highest energy efficiency rate	May requires foreign contractors and funding
Creates employment opportunities and saves fuel	
Do not fluctuations in market.	
Social aspects	
Leaves water available for other uses	May involve resettlement around dams
Provides food protection	May restrict navigation
Provides irrigation in agriculture	Local land use patterns will be modified water
May enhance navigation conditions	Waterborne disease symptoms may need to be checked
Usually enhance entertainment area	Requires management of competing water uses
Extension accessibility of the territory and its sources	Who lives towns that in a valley that to be flooded, loss
Improves living conditions	Dams constructed blocking the flow of a river/stream through in the following country
Sustains livelihoods (fresh water, food supply)	
Increase settlement	
Provides job opportunities	
Large dams become tourist attractions/ pleasure and sport activities	
Environmental aspects	
Produces no pollutants but only very few GHG emission.	Food disaster of terrestrial habitat
Increase air quality	Modification of hydrological regimes
Produces no waste and harmful emission	Modification of an aquatic animal or plant lives
Avoids depleting non- renewable fuel resources	Water quality needs to be managed
Often create new freshwater ecosystems with increased productivity	Species activities and populations need to be monitored
Increase knowledge and improve management of valued species owing to study results.	Barriers for fish migration
Helps to slow down climate change	Sediment composition and transport may need to be monitored
Neither consumes nor pollutes the water it uses for electricity generation purposes	Large dam may alter the natural water table level.
Contributes to fresh water storage	Depends on the rainfall, which varies from year to year.
Others	
Consist of only wheels, buckets and river flow	

6.2. Small hydropower's effect on the environment

The use of renewable energy resources is the most valuable solutions to reduce the environmental problems. Hydro, wind, biomass, solar, and geothermal energy sources are a clean source of energy. There are no problems with air pollution, chemical runoff, and toxic waste.

Small hydropower can be installed in river, sharp valleys, stream, dams and canals with small apparent environmental effects. Minimizing the environmental effects and maximum water conservation potential has been given to the development and installed hydropower plants systems. Small hydropower is a key factor for sustainable development owing to the following reasons [47].

- Suitable utilization of water sources; a lot of streams and rivers can safely provide energy to perform a small hydropower plants. Because, there is not water storage in such projects that prevents settlement of the population.
- As a renewable and sustainable energy source, small hydropower; uses the energy of flowing water for production of electricity.
- Small hydropower is cost effective; running small hydropower systems is simple and low-cost of occupation. Installation period is short with projects giving financial returns quickly.
- Helping development and advance of the rural areas; small hydropower plants are particularity suitable for the remote, rural areas which relies on its hydropower potential. Eastern Black Sea Region has small hydro or hydropower sources. Small hydropower is environmentally friendly option for generating electricity.
- Clean and non polluting source; One of the most important reasons for operate hydropower is a clean and non polluting sources. Because, they are known for less carbon energy production. Small hydropower is a pollution free source for environment problems like GHG emission, acid rain are not associated with it for globe warning and acid rain.
- Utilization of small hydropower dams for irrigation, water supply and flood prevention.

On the other hand, the main disadvantage of hydropower is that, when the impact of small hydropower plants monitored on the environment impact, small hydropower plants have effects on natural environment. They block the connection between upstream and downstream of the facility. Therefore, fish populations can be impacted which means that fish cannot migrate upstream dams to spawning grounds.

7. Evaluation of Turkish hydropower policy

General purpose of the energy policies is to answer the energy needs of increasing population and growing economy at minimum costs. The specific national energy strategy document and energy policy objectives are outlined in the institutional strategic plan 2010–2014 of the Turkish Ministry of Energy and Natural Resources. These strategies include; energy supply security, regional and global influence in the area of energy and environment protection. Primary targets of the government are to ensure sufficient energy to a growing economy. In addition, the aim of the energy policy is to expand the utilization of energy resources for generating electrical energy, to benefit from all resources in secure, economic and qualified manner, to increase the diversification of energy resources, to reduce greenhouse gas emissions, to utilize waste products, to protect the environment and to develop the related manufacturing sector [10,48].

Turkey is a candidate to become a member of European Union. Thus, it is expected that the laws of Turkey have to be compatible with European Union laws and policy. The electricity Market Law brought Turkish legislation in line with that of the European Union (EU). The Energy Market Regulatory Authority (EMRA) took over responsibility for the electricity market in 2002. Eventually it is expected to supervise a free market in which private sector produce electricity and sell it to private trading companies. On the other hand, the government meanwhile is required to privatize generation assets that are including hydro sources which account for about 57.3% of total producing capacity. Turkey's law and regulation with relevance to the use of renewable energy sources is only two pieces of legislation. The first is the Electricity Market Licensing Regulation, and the second is the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy (Law Number 5346, in 2005). In the regulations, only small hydropower plants are included in the definition of renewable energy resource. Law No. 5346 regards any hydro plant with a reservoir area less than 15 km^2 as renewable energy source and there is no limitation for installed capacities. This causes interest of private sector to change from river type hydropower plants to large hydropower plants because of potentially higher profit rates. For example, Koprubasi Dam, which is situated on the West Black Sea Region, having a height of 108 m, a reservoir area of 5.9 km^2 and 79 MWof installed capacity currently lies within the outline of this law [25,42]. However this creates a conflict between Turkey and the EU policy. In European Union Member States, countries limit the installed capacity and give the sector extra payments if they build SHP plant Table 19 lists government support for electricity generation for SHPs in some European countries [49].

The impact of small hydropower plants on natural environment must be closely monitored, and laws and regulations must be published by governments to minimize the negative effects. In Turkey, the facility should conform to the requirements of Water Usage Rights Act signed between the private sector and DSI. According to this act, the facility should maintain a minimum flow determined by DSI in the river that is adequate for the existing fish population, wildlife and water quality taking seasonal fluctuations in flow levels into account. However, there is not a limit for application of the environmental flow and there is not a facility to contribute to deterioration of water quality both upstream and downstream of the facility in Turkey. Therefore, this condition may cause loss of fish [16,42].

In Turkey, the publication of Electricity Market Law (Law No. 4628) of March 2001 led to the establishment of Electricity Market Regulatory Authority. This brings along private sector

Table 19
Government support for electricity production small hydropower plants in some European courtiers.

Country	Feed- in trariff[a] (€cent/kW h)
Belgium	12.5
Germany	7.67 (< 500 kW)
	6.65 (500 kW–5 MW)
Greece	6.29
Spain	6.49
France	11.57 (< 500 kW)
	10.48 (500 kW–12 MW)
Ireland	6.41
Italy	14.6
Austria	3.15–6.25
Portugal	7.2
Finland	3.02 + subsidy of 30% of investment cost (1 NW)
Sweden	4.9
UK	2.38 (20 MW)
Turkey	5.5 (no limitation on installed capacity)

Table 20
Turkey new energy laws concerning the small hydropower development.

Law no	Publication date	Objective	Contribution
4628	March 2001	To ensure the development of a financially sound and transparent electricity market operating in a competitive environment	The Electricity Market Regulatory Authority had been established. Private sector legal entities should obtain a license from Energy Market Regulatory Authority to be engaged in the market; to build a power plant and to operate it
5346	May 2005	Promotion of the use of renewable energy resources for electric generation	Government guarantees the buy the electricity with a price of 5–5.5 €cent/kW h for 10 years from legal entities which are holding a renewable energy source certificate
5784	July 2008	Promotion of a more efficient electricity market	Legal entities are not required to apply for a license, or to formally incorporate their activity to generate electricity from renewable energy up to a capacity of 500 kW and government guarantees the buy the excess electricity

legal entities to obtain a license granted from this authority to build and operate a power plant. Moreover, after the publication of Renewable Energy Law (Law No.5346) of May 2005, government guarantees to buy electricity from legal entities with a price of 5.5 €cent/kW h for duration of 10 yr. Besides, 85% discount has been being applied for forest land acquisition to build SHP plants. The effect of this law has been immediately seen after its publication on small hydropower plants development resulting in a total of 1024 project applications with an installed capacity of 6500 MW by private sector in Turkey. The publication of this law also can be considered as an important step in harmonizing Turkish legislation with that of European Union. After that, in July 2008, Law No.5784 was published stating that the legal entities are not required to apply for a license to generate electricity from renewable energy up to a capacity of 500 kW and government guarantees the buy the excess electricity. Also, the publication of this law allowed legal entities to be exempted from obtaining license to generate electricity from renewable energy up to a capacity of 500 kW. By this law, government also guarantees to buy the excess electricity. It can be expected that this law will also give rise to an increase in installation of mini and micro-hydropower plants in coming years, as seen in Table 20 [16,42].

The aim of the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy is to increase the use of renewable energy sources for generating electricity, as well as to diversify energy resources, reduce greenhouse gas emissions, assess waste products, protect the environment, and develop the necessary manufacturing sector for realizing these objectives.

8. Conclusions

Turkey does not have enough primary energy sources such as fuel oil and natural gas reserves, but has an abundant hydropower energy potential to exploit for meeting its increasing energy demand. Therefore, there is growing interest for the development of its substantial hydropower potential. The gross hydropower potential of Turkey is about 433TW h/yr, which is equal to 14% of European hydropower potential. Almost half of the gross potential is technically exploitable. Turkey has technical and economical hydropower potential of 216 TG h/yr, and 140 TW h/yr, respectively. Currently, there are 228 hydroelectric power plants in operation with a total installed capacity of 14,503 MW. Major Turkish hydro dams are Ataturk dam (2405 MW installed capacity), Karakaya dam (1800 MW), Keban dam (1330 MW).

- Turkey's hydrological, geography and topographical conditions are suitable to establish hydropower plants. Eastern Black Sea Region is the one of the important basin of Turkey for small hydropower energy potential. The total amount of installed capacity and annual average energy generation of the 296 hydropower plants in the region are 4585 MW and 16160 GW h/yr, respectively. 181 of these plants are the small hydropower plants which have a total installed capacity and annual average energy generation of 861 MW and 3213 GW h/yr, respectively.
- The great advantage of the region basin in terms of small hydropower potential is the highest annual average precipitation upon 4 times the average it reserves in Turkey. Moreover, the region is covered by very sharp valleys and a numbers of very steep streams with important amount of flow rate and head. The sharp valleys and steep streams are exactly very important for small hydropower plants. Because, small hydro powers are installed in most cases run-of-river. Small hydro dams are quite small and usually just a little weir. Since they do not store the water, they have minimal adverse effect on the local environment compared with large hydropower.
- The most important characteristic of the region precipitation is that it takes great amount of rainfall in every season. The values of the average annual precipitation in the region's cities are as followed, 2242 mm for Rize, 1258 mm for Giresun, and 1034 mm for Ordu. However, Turkey's annual average precipitation is 641 mm.
- Hydropower produces essentially no carbon dioxide or other harmful emissions to environment. Today, growing concern for increasing greenhouse gas emissions and increased demand for energy, hydropower plays a major role in energy policies of countries with abundant water sources. The others significant benefits of hydropower are control flood prevention, regulate water supply, increase air quality, improve living conditions, contributes fresh water storage, reduce greenhouse gas, irrigate land and prevent erosion.
- In Turkey, the publication of Electricity Market Law (Law No. 4628) of March 2001 led to the establishment of Electricity Market Regulatory Authority. This brings private sector legal entities to obtain a license granted from this authority to build and operate a power plant.
- The publication of Renewable Energy Law (Law No.5346) of May 2005, government guarantees to buy electricity from legal entities with a price of 5.5 €cent/kW h for duration of 10 years. 85% discount has been being applied for forest land acquisition to build SHP plants.
- Finally, Law No. 5784 published in July 2008 allowed legal entities to be exempted from obtaining license to generate electricity from renewable energy up to a capacity of 500 kW. By this law, government also guarantees to buy the excess electricity. It can be expected that this law also will give rise to an increase in installation of mini- and micro-hydropower plants in coming years.

- The aim of the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy is to increase the use of renewable energy sources for generating electricity, as well as to diversify energy resources, reduce greenhouse gas emissions, assess waste products, protect the environment, and develop the necessary manufacturing sector.

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